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DEFLATION BASIN IN THE COASTAL AREA OF THE SECHURA DESERT, NORTHERN PERU

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INTRODUCTION

General statement. The basin described in this report is a unique feature of the coastal geography of Peru, would be unusual in any desert coast, and could occur only in a region of negligible rainfall. It is significant both from the standpoint of descriptive geography, and for its bearing on unsettled questions as to the effectiveness of eolian erosion in producing landforms of appreciable magnitude. In this report it is therefore proposed to place on record the significant features of the basin, to discuss its mode of origin, and to make comparisons with other regions.

Location. General location in Peru is shown in Fig. 1, and location within the Sechura Desert is shown in Fig. 2. The center of the basin is about 18 kilometers from the Pacific coast, and the margin about 10 kilometers. The locality is comparatively inaccessible, and can be reached only by Jeep or other type of vehicle equipped for desert driving, and following unmarked, unimproved trails and proceeding cross-country. The nearest town of any size is Piura, about 90 kilometers to the north, and on the Pan-American Highway; the best approach to the basin is from Piura.

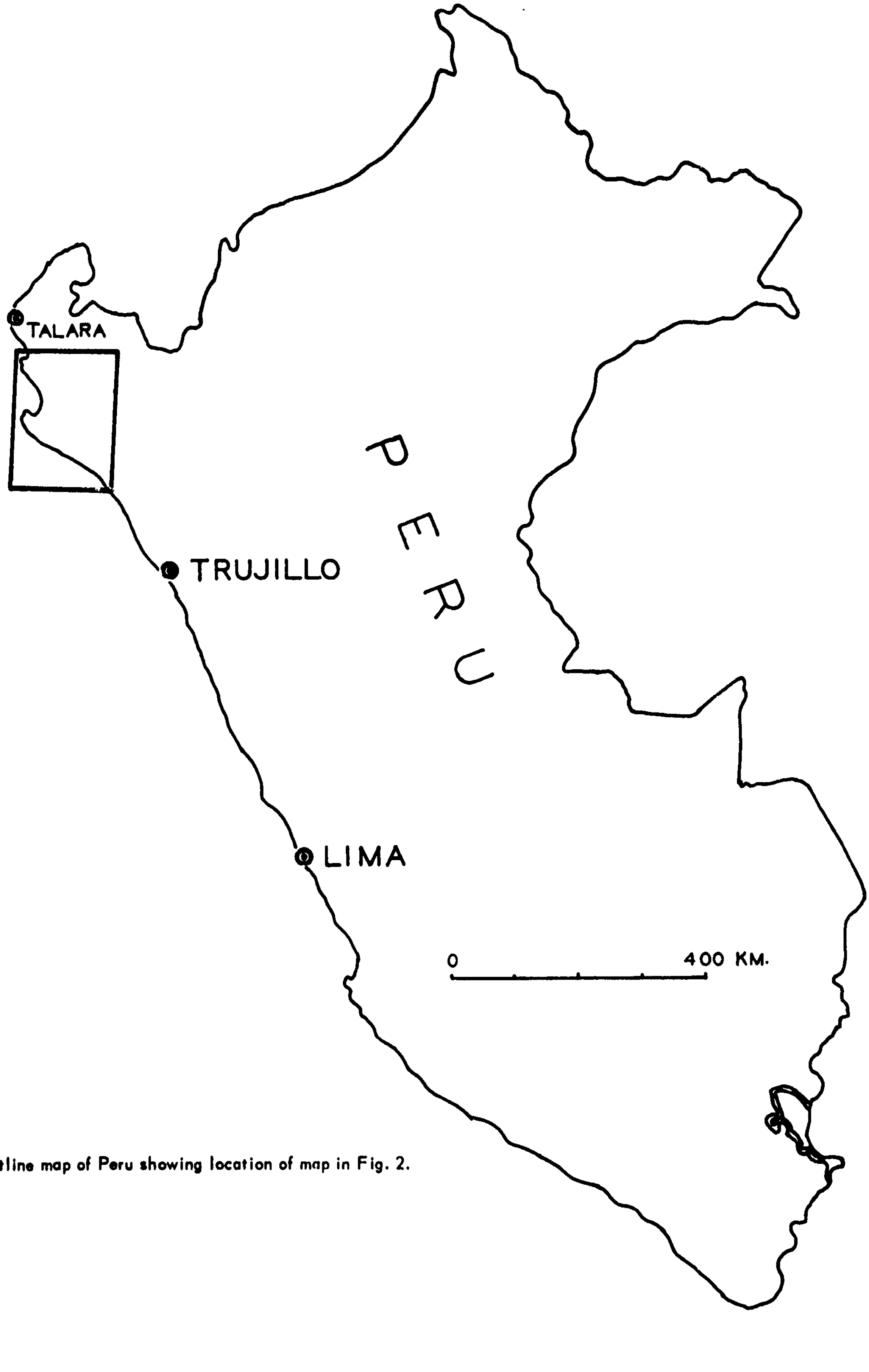

Fig. 1. Outline map of Peru showing location of map in Fig. 2.

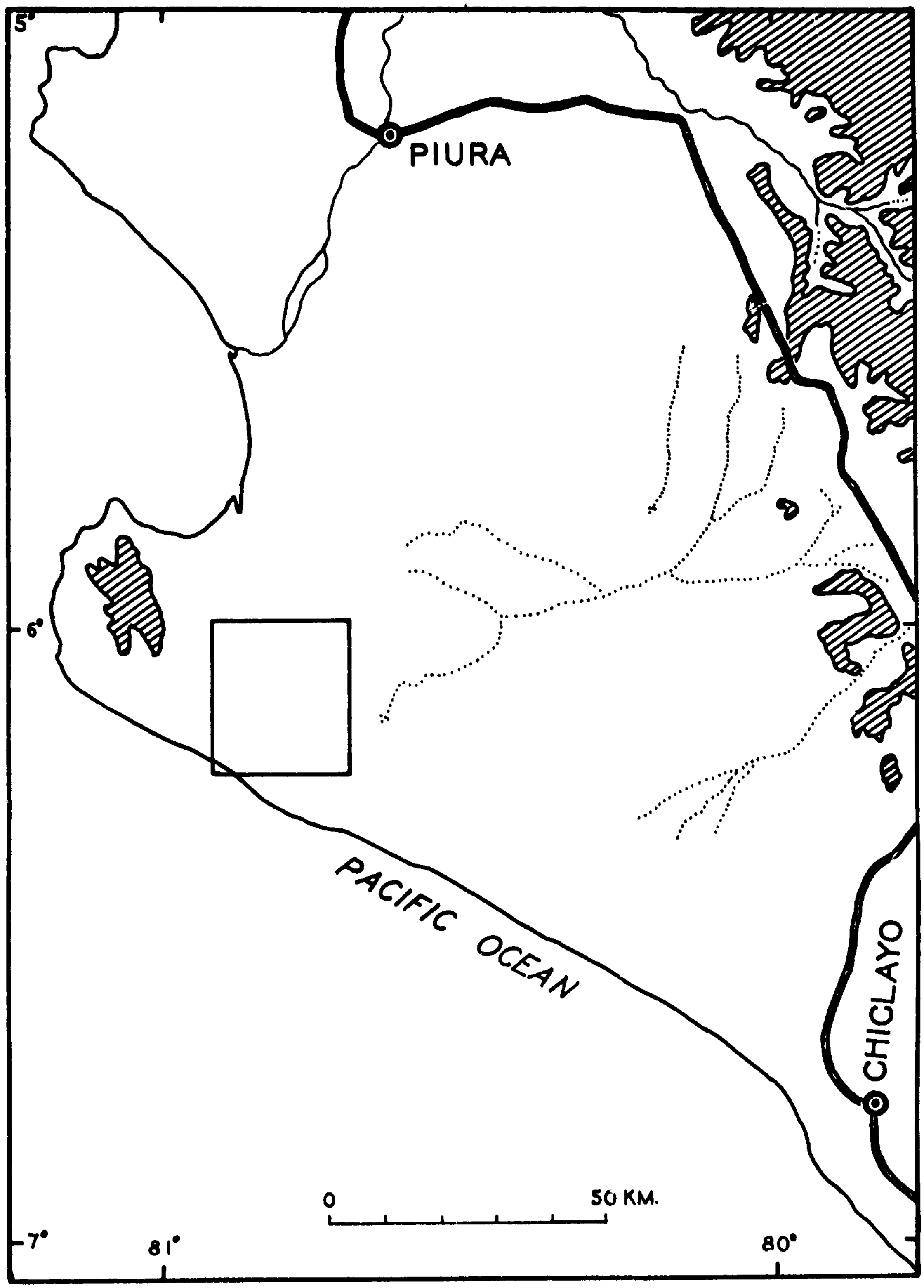

Fig. 2. Map of the Sechura Desert showing location of detailed map in Fig. 3; areas above the 1000-foot contour are crosshatched; the double line represents the Pan-American Highway; based on World Aeronautical Chart 1011.

Climate. Climatic data are meager. In general, rainfall is slight, but erratic; interspersed with typical years of negligible precipitation are occasional years of violent flooding. James (1942, p. 172-174, 851) reports an average annual precipitation of 0.7 in. over a period of about 4 years, at Chiclayo. Some moisture is supplied also by heavy mists. At irregular intervals of years, exceptional storms bring excessive rainfall; at Trujillo, with a total rainfall of only 1.4 in from 1918 to 1925, there was a total precipitation of 15.5 in. during March of 1925, with 8.9 in. in the 3-day period from the 7th to the 9th of that month. Torrential episodes of comparable magnitude are recorded also for the years 1878, 1884, 1891, 1918, 1932, and 1939.

Temperature is relatively equable. At Chiclayo, during the period 1909-1912, average monthly temperatures ranged from 63.5°F. to 78.3°, and the annual average was 69.8° (James, 1942, p. 851).

Data on winds must be drawn largely from the occurrence of sand dunes. The orientation of the dunes indicates that the dominant winds are from the south, and the widespread occurrence of active dunes points to the frequency of strong, sand-moving winds. One sand storm, carrying sand to a height of about 4 feet above the ground, was observed in August, and probably is typical. Dust storms are reported also from the northern part of the Sechura Desert.

Field studies. Field work on which this report is based was of a reconnaissance character, carried out during 3 days in August of 1954, as part of a more general investigation of eolian phenomena in the coastal desert of Peru. Subsequent study of air photos provided much additional information.

Base maps. The best available maps for the area herein described are air photo mosaics, on a scale of approximately 1:30300, issued by the Servicio Aerofotografico Nacional of Peru (Proyecto No. 1626); these were studied before entering the field, but were not available for use in the field. While in the field, the following maps were used: World Aeronautical Chart No. 1011, on a scale of 1:1,000,000, and a map of petroleum concessions, on a scale of 1:500,000, issued by the Ministerio de Fomento y Obras Publicas, Direccion de Petroleo.

Acknowledgments. Particular thanks are due to Dr. Alfred G. Fischer for hospitality, aid, and background information as preparations were being made for field work, and specifically for pointing out the problems of the basin described in this report; his help contributed greatly to effective use of the limited time available for field study. Other officials of International Petroleum Company aided the project in many ways, particularly by the loan of field equipment and by extending the use of office facilities in Lima, commissary and guest facilities in Talara, and field camps in the Sechura Desert. The Servicio Aerofotografico Nacional, in Lima, permitted study of their collection of air photos of the region, and supplied the mosaics and prints used subsequently in the laboratory. Lyndon Bell, Jr., gave able service as field assistant and translator.

STATUS OF THOUGHT ON WIND EROSION

Problems relating to the basin in the Sechura Desert may best be viewed in the light of previous observations and ideas on eolian erosion. Although the effectiveness of wind action in abrading rock surfaces was noted by Blake as early as 1855, it was not until 1875 that the possibility of wind being a major agent of erosion in arid regions was suggested, by Gilbert, on the basis of observations in the Colorado Plateau region. A few years later, the same general idea was expressed independently by Pumpelly (1879), as a corollary of Richthofen's theory on eolian origin of Asiatic loess. Still later, the idea was greatly extended by German workers in Africa (Walther, 1891; Passarge, 1904) with more enthusiasm than discretion. In 1905, Davis assigned to eolian erosion an important place in the advanced stages of the erosion cycle in arid regions. This was followed, in North America, by a wave of unquestioning acceptance, with the result that wind action was given a dominant role in developing topographic features of the southwestern plateaus and the Basin and Range province (Keyes, 1908; Hill, 1908; Cross, 1908; Free, 1909, 1911; Matthew, 1915). A more moderate estimate of eolian erosion was given by some other workers, however (Tolman, 1909; Meinzer, 1915), and various supposed evidences of that process were discarded subsequently by Gregory (1917), on the basis of more detailed observations. Still later, a critical reappraisal by Bryan (1923) placed the matter in better perspective, and led to the conclusion that occurrences of undoubted eolian erosion on a large scale were far more limited geographically and climatically than had been supposed. Studies on other continents, both before and after Bryan's work, together with subsequent studies in North America, have led to better understanding of the criteria for wind action and to further delimitation of the types of features and the geographic occurrences which may properly be attributed to eolian erosion. However, the earlier myth lingers on, and textbooks concerned with physical geology and even with geomorphology still present exaggerated claims as to the role of wind erosion in desert regions.

Of the types of features which have best withstood the test of critical reexamination as valid examples of eolian erosion, various occurrences of enclosed basins are by far the most significant in terms of areas covered and numbers reported. However, much still remains to be learned about their geographic distribution and their detailed characteristics, and it is in this connection that the feature described in this report is of particular interest.

TOPOGRAPHIC AND GEOLOGIC SETTING

The Sechura Desert lies in a broad expanse of coastal lowland bordered on the east by an abrupt rise to rugged hills and mountains. Locally on the western side, near the basin herein described, there is a small area of rugged coastal hills. The surface is irregular in detail, with local relief of some tens of meters, but the general aspect is one of flatness. Although detailed topographic maps are lacking, reconnaissance observation indicates a general rise from west to east, with elevations of the order of meters to tens of meters near the coast, and upwards of 100 meters toward the east. In the vicinity of the undrained basin, the regional slope has a southerly component. Except for the Rio Piura and Rio Chira toward the north, no streams cross the area. Smaller streams entering from the east gradually lose their waters and their identity across the desert. Much of the area appears to have no surface drainage.

On the desert, sand dunes are the most conspicuous feature. Within the area considered in this report, barchans are the dominant type, and composite barchans occur at a few places. The desert surface between the dunes is sandy to gravelly. Vegetation is limited to a few widely scattered bushes.

The greater part of the desert surface is mapped as Quaternary (Eleodoro, 1956), with several outcropping areas of Miocene in the area considered here. The latter is essentially flat-lying, and consists of unconsolidated to semiconsolidated, fine-grained sediments, mainly diatomaceous shale.

DESCRIPTION OF THE BASIN

The general nature of the basin is shown in Fig. 3. Maximum length is approximately 19 kilometers, and width is up to slightly more than 10 kilometers. A total area of about 160 square kilometers lies below sea level, and roughly half of this is below the -20 meter contour. The maximum depth of the basin is about 24 meters below sea level, and the maximum local relief from floor to rim is about 40 meters or slightly more.

The outline of the basin is very irregular, with many salients and reentrants along the bordering slopes, particularly on the northern side, where their width reaches about one fifth of the average width of the basin. Superimposed on the broader irregularities are innumerable minor notches, giving the rim a very ragged form in detail at most places. In general, the basin is widest at the east and narrows toward the west, terminating there at a broad,

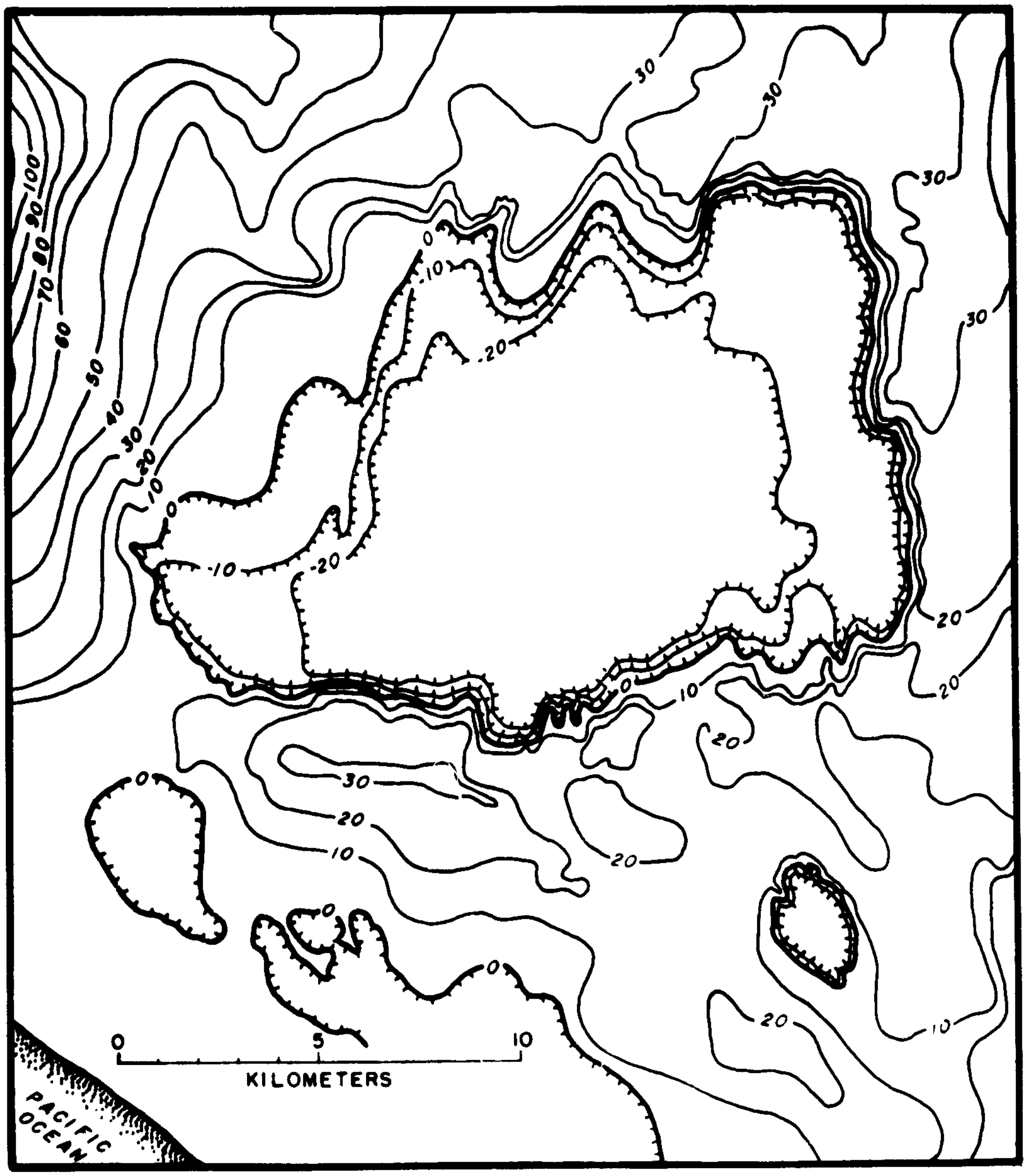

Fig. 3. Contour map of the inclosed basin and surrounding area, redrawn from map compiled by F. Zuniga y Rivero, of the International Petroleum Co., from elevations of gravity meter stations and other data. Contour interval is 10 meters.

lower gap leading out to the coast.

The slopes encircling the basin are steep and abrupt at most places, but differ considerably in height. Maximum height is around the eastern part of the basin, and ranges up to slightly more than 40 meters. Toward the gap at the west, however, this decreases to about 10 meters. Along the northwestern side of the basin, the bordering slopes lose their abruptness and distinctiveness, and merge gradually into the slopes of the surrounding terrain. At some places, particularly along the northeast and southeast, the slopes have a stepped profile, controlled apparently by differential erodibility of the bedrock. Minor gulleying of the slopes is extensive, and intricate in pattern. Bedrock is exposed wherever the slopes are very steep, except where mantled by eolian sand. Falling dunes and narrow, pointed lee dune ridges occur at many places along the southern slopes, and, where the sand is abundant, these pass into barchan trains on the floor of the basin.

The basin receives some drainage from a narrow, irregular band of surrounding territory, particularly on the north side, where dry stream channels, sharply incised, extend a few kilometers back from the rim of the basin. They immediately lose their identity, however, on reaching the floor of the basin.

The floor of the basin is remarkably flat, except where interrupted by dunes and by bedrock hills. The surface ranges from sandy to clayey, and from dry to moist. Saline incrustations are found in the lower sections. With proper care, the greater part of the floor is passable by jeep.

The dunes on the basin floor are mostly barchans, generally less than 5 meters in height, occurring in long, narrow trains trending north-south for various distances from the south side. Movement is toward the north. Toward the west, one huge, asymmetric composite barchan extends more than half way across the basin. Associated trains of simple barchans are particularly broad in adjoining areas, and one merges with the east arm of the composite barchan. To the leeward of this area, a great number of simple barchans are moving across the northern border of the basin.

The bedrock hills of the basin floor are found mostly near the eastern and northeastern sides. They range in length from a few tens of meters or less up to more than one kilometer. The smaller ones are of streamlined form, oval in outline and with a rounded cross profile, and elongated in a north-south direction. The larger ones are irregular in form, higher, and commonly flat-topped; the borders of many are notched by miniature gulleys. On both large and small hills, the sides show minor irregularities due to differential erosion of beds of differing resistance. The lower flanks, up to a height of a few meters, commonly display the smoothed and fluted surfaces characteristic of eolian erosion.

Associated with the major basin are other smaller depressions of considerable interest. The largest is situated about 7 kilometers south of the southeastern corner of the large basin. It is approximately 3 kilometers long, 2 kilometers wide, and 20 meters deep, and the floor is below the -10 meter contour. It is continuously rimmed by a steep, intricately notched bluff, which decreases in height from north to south. A smaller, shallower enclosed depression adjoins the main basin at the northeast corner.

Its length is about one kilometer, and its breadth somewhat less. Topography of the adjacent part of the main basin suggests the possibility of coalescing of one or more such smaller basins with the main one.

ORIGIN OF THE BASIN

Undrained basins, in general, may be formed by (1) meteor impact, (2) subsidence, or (3) erosion, or by some combination of these processes. In the case of the Sechura basin, the first of the above possibilities is excluded by the absence of structural disturbance, raised rim, and other characteristics associated with depressions of demonstrable meteoritic origin.

Basin-forming subsidence might be produced either by tectonic movement or by solution and collapse. Direct evidences of the former are lacking at the Sechura basin. No deformation of the strata outcropping around the basin can be detected by the eye, and the abrupt transection of the strata by surface slopes cannot be explained on the basis of tectonic factors alone. There remains a possibility, however, that a very gentle downwarp might have been a factor in localizing the basin and setting the stage for other processes to do their work; until detailed geologic mapping of the area has been carried out and made available, however, this possibility cannot be evaluated adequately.

Subsidence produced by solution and collapse is competent to produce basins similar in general form to that here discussed, where a sufficient thickness of soluble rock occurs at sufficiently shallow depth. In the Sechura area, however, drilling in connection with petroleum exploration has failed to reveal any soluble strata within depths of several thousand feet. Furthermore, drooping or slumping of beds in peripheral outcrops, such as is commonly associated with solutional depressions, is nowhere to be seen.

Erosional origin remains to be considered. Any explanation on this basis, must account for the removal of a great volume of detrital material from a broad but strictly localized area, to a depth of more than 20 meters below sea level. The occurrence of minor dry stream channels around the sides of the depression indicates that stream erosion has played some part, but whether this has been of a primary or a secondary nature is another question. Conceivably, stream erosion might have reduced the basin floor to a gradient controlled by local baselevel, as represented by the bottom of the gap at the western end, at an elevation of between 10 and 20 meters above sea level. Granting this, it might be supposed further that, during times of lowered sea level accompanying Pleistocene glacial stages, stream erosion might have worked to a lower baselevel than at present, discharging through a valley which subsequently was filled up by shore deposits as sea level rose to its present stand. However, when confronted by the topographic facts of the situation, this hypothesis proves to be entirely inapplicable. Stream erosion normally progresses along a definite drainage network, characterized by a trunk stream and a system of tributaries. Unless controlled by clear-cut and unmistakeable structural factors, or by antecedent topography produced in other ways, it does not work outward piecemeal in all directions from a central point or axis, through the sole agency of minor streamlets of essentially equal rank. The normal product of stream erosion is an integrated valley system and not an abruptly delimited basin. Furthermore, detailed examination of air photos shows that the morphology at the western end of the basin is essentially similar, except for scale, to that on the other sides, and finds no traces of any former stream channel through the gap, or any topographic indications of shore deposits which might have plugged a buried valley. Finally, the hypothesis of stream erosion is obviously inapplicable to the smaller, satellitic undrained basin, for which no former drainage connection with the ocean can be invoked. It must be concluded therefore, that stream erosion is to be relegated to a subordinate role, contingent on and conditioned by some other dominant process.

Elimination of other possibilities leaves eolian erosion as the more probable basis for an explanation, and confirmation is found in both direct and indirect lines of evidence. Direct evidences are provided by observable products of eolian erosion and transportation: grooved and fluted surfaces on bedrock hills of the basin floor, "streamlined" hills of the jardang type, elongated parallel to the direction of dune movement, the widespread distribucion of active sand dunes in and around the basin, and the occurrence of sand storms in the general area. All of these point to the effectiveness of wind action during the present and recent past. Projection farther back in time rests on indirect evidences, of which the following may be listed: (1) the presence of a type of bedrock particularly susceptible to erosion and removal by wind; (2) the prevalence now, and by inference for extended intervals during the past, of climatic conditions especially favorable for wind action; (3) the fact that wind action is the only agent capable of working below sea level, and of removing material in an uphill direction; (4) extensive deposits of eolian sand grading into silt, in the northern and northeastern sections of the Sechura Desert, which appear to represent possible depositional correlatives with the excavation of the basin; (5) similarity between the characteristics of this basin and those of depressions in North Africa and elsewhere which are generally accepted as products of eolian erosion.

It may therefore be concluded that eolian erosion, involving both abrasion and deflation, provides the only satisfactory explanation for the development of the Sechura basin. Stream erosion around the margins undoubtedly played a part in supplying detrital material and carrying it to the floor of the basin, thus making for easier pickup by the wind. At present, wind action is more or less constant, while stream erosion is limited to brief episodes widely separated in time. However, it is possible that, during the wider climatic fluctuations of the Pleistocene, there were more extended intervals of humid conditions, in which stream action was dominant, alternating with more arid conditions, in which wind action was dominant. Alternation of the two processes would have made for maximum effectiveness of the excavation process. It is possible also that, either as a result of more humid conditions in past times, or because of inflow during higher stands of sea level during interglacial stages, that the basin was occupied by standing water at some times. In that event, wave erosion may have played some part in extending the limits of the basin. Until borings are made in the basin floor, and samples studied, these possible phases of basin history must remain speculative. The same applies to the question as to the initiation of the basin and the reason for its localization. Some antecedent topographic sag, produced perhaps by gentle downwarping, would be a plausible surmise.

COMPARISON WITH OTHER AREAS

The great depressions of the Libyan Desert (Western Desert of Egypt) are the largest, deepest, most numerous, and longest-studied features available for comparison (Hobbs, 1917; Ball, 1927; Said, 1962, p. 13-14), and are generally accepted as having been produced primarily by eolian erosion, with other processes in a contributing role. Comparison may be made in numerical terms as follows, with data for the Libyan depressions according to Ball (1927, p. 25):

Depression	Approx. area below sea level in sq. km.	Approx. max. depth below sea level in meters
PERU: Sechura basin	160	24
LIBYAN DESERT:		
Wadi Natrum	220	23
Faiyum	700	45
Wadi Rayan	280	43
Quattara	18,000	134
Sittra	300	33
Bahrein	150	15(?)
Watiya	70	15
Areg	60	25
Siwa	800	17

Undrained basins of considerable size in central Asia have been attributed to wind action (Pumpelly, 1879; Berkey and Morris, 1927), but available information is insufficient for particularized comparison.

In North America, comparatively few occurrences are available for comparison. Among the largest definitely attributable to eolian erosion are those in the High Plains of Texas (Evans and Meade, 1945), which range up to several square miles in area; lack of detailed topographic maps, however, precludes comparison in terms of depth. Smaller depressions of a comparable nature have been described from eastern New Mexico by Judson (1950). In the Laramie Basin of Wyoming, an elongate enclosed basin some 15 square miles in area, and up to 150 feet deep, has been ascribed to eolian erosion by Blackwelder (1909). In the Mojave Desert of California, the effects of deflation in lowering playa floors though without development of actual enclosed basins, has been described by Blackwelder (1931).

CONCLUSIONS

The enclosed basin of the Sechura Desert is best explained on the basis of eolian erosion and deflation as the major process, with minor stream erosion around the margins supplying material in a form and to a position most favorable for eolian pickup. Lowering of the floor may be attributed entirely to eolian erosion, and recession of the encircling bluffs mainly to running water, with eolian erosion possibly in an auxiliary role. Irregular, short-time alternations between fluvial and eolian processes are inferred at the present time, and more pronounced alternations of longer duration probably accompanied the wider climatic swings of Pleistocene time.

The basin is comparable in size with the oasis depressions of the Libyan Desert, and is the largest feature of its kind in the Western Hemisphere thus far studied. It adds one more significant example to the list of demonstrable products of eolian erosion, and this in an entirely new geographic region having its own distinctive climatic environment.

REFERENCES

Ball, John, (1927). Problems of the Libyan Desert: Geog. Jour., vol. 70, p. 21-38.

Berkey, C. P., and Morris, F. K., (1927). Geology of Mongolia, in: Natural History of Central Asia, Vol. 2, p. 325-326. (Amer. Mus. Nat. Hist., N.Y.

Blackwelder, Eliot, (1909). Cenozoic history of the Laramie Basin, Wyoming: Jour. Geol., vol. 17, p. 443.

------------------- (1931). The lowering of playas by deflation: Amer. Jour. Sci., vol. 21, p. 140-144.

Blake, W. P., (1855). On the grooving and polishing of hard rocks and minerals by dry sand: Amer. Jour. Sci., vol. 20, p. 178-181.

Bryan, Kirk, (1923). Wind erosion near Lees Ferry, Arizona: Amer. Jour. Sci., vol. 6 (5th ser.), p. 291-307.

Cross, C. W., (1908). Wind erosion in the plateau country: Bull. Geol. Soc. Amer., vol. 19, p. 53-62.

Davis, W. M., (1905). The geographical cycle in an arid climate: Jour. Geol., vol. 13, p. 380-407.

Eleodoro, B. B., et al (1956). Mapa Geologico del Peru, 1:2,000,000: La Sociedad Geologica del Peru.

Evans, G. L., and Meade, G. E., (1945). Quaternary of the Texas High Plains: Univ. Tex. Publ. 4401, p. 485-507.

Free, E. E., (1909). A possible error in the estimates of the rate of geologic denudation: Science, vol. 29, p. 423-424.

------------ (1911). The movement of soil material by the wind: U. S. Dept. Agric., Bur. Soils Bull. 68, p. 38-41.

Gilbert, G. K., (1875). Report upon geographical and geological explorations and surveys west of the one hundredth meridian, vol. 3, part 1, p. 82-84: Engineer Dept., U. S. Army, Washington, D. C.

Gregory, H. E., (1917). Geology of the Navajo country: U. S. Geol. Surv. Prof. Paper 93, p. 138.

Hill, R. T., (1908). Growth and decay of the Mexican Plateau: Eng. Min. Jour., vol. 85, p. 681-688.

Hobbs, W. H., (1917). The erosional and degradational processes of deserts, with special reference to the origin of desert depressions: Ann. Assoc. Amer. Geog., vol. 7, p. 25-60.

James, P. E., (1942), Latin America, p. 171-174, 851, Odyssey Press.

Judson, S., (1950). Depressions of the northern portion of the southern High Plains of eastern New Mexico: Bull. Geol. Soc. Amer., vol. 61, p. 253-274.

Keyes, C. R., (1908). Rock-floor of intermont plains of the arid region: Bull. Geol. Soc. Amer., vol. 19, p. 63-92.

Matthew, W. D., (1915). The Tertiary sedimentary record, in: Problems of American Geology, Yale Univ. Press, p. 379-381.

Meinzer, O. E., and Hare, R. F., (1915). Geology and water resources of Tularosa Basin, New Mexico: U. S. Geol. Surv. Wat. Sup. Pap. 343, p. 44-45.

Passarge, S., (1904). Die Inselberglandschaften im tropischen Afrika: Naturwiss. Wochensch., vol. 3 (new ser.), p. 657-665.

Pumpelly, R., (1879). The relation of secular rock-disintegration to loess, glacial drift and rock basins: Amer. Jour. Sci., vol. 17 (3rd ser.), p. 133-144.

Said, Rushdi, (1962). The Geology of Egypt, Elsevier Publ. Co., Amsterdam, p. 13-14.

Tolman, C. F., (1909). Erosion and deposition in the southern Arizona Bolson region: Jour. Geol., vol. 17, p. 136-163.

Walther, J., (1891). Die Denudation in der Wüste: Abh. der math.-phys. Cl. König. Säch. Gesell. der Wiss., Bd. 16, no. 3, Leipzig, p. 347-569.